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Observations by Time Frame: Day Ahead & Overall Operation

- Unit Commitment
  - An economically rational unit commitment that includes intermittent resource forecasts results in sufficient flexibility for successful operation
    - Forecasting increases value of intermittent resources by $4.37/MW-hr
  - Economic inefficiencies introduced by ignoring intermittent resources in DAH unit commitment is an order of magnitude greater than variable cost benefit of intermittent renewables
  - Operational Economics
    - Variable production cost reduction is $760M in CA, $1,950M in WECC
    - Load payment reduction is $2.91/MW-hr (of load) in CA, $2.42/MW-hr in WECC
    - Non-renewable revenue reduction is $1,200M in CA, $3,900M in WECC
- Emissions and Displacement
  - NOx reduction is 520 tons in CA, 4000 tons in WECC
  - SOx reduction is 700 tons in CA, 2000 tons in WECC
  - Natural gas reduction is 140 B CuFt/yr in CA (~8 million tons CO2), 390 B CuFt/yr in WECC (~23 million tons CO2)

Observations by Time Frame: Schedule Flexibility (Hourly)

- 1 hour Variability and Schedule Flexibility Requirement (3σ)
  - In general, schedule flexibility requirement increases about 8%, or by about 390MW per hour, to ~5100MW
  - For light load, schedule flexibility requirement increases about 47% (to ~3200MW)
    - This is 70% of the ~4700MW year-round requirement w/o intermittent renewables
    - About 20% of hours have a net load less than load-only minimum
  - Use of pumped storage hydro increases
    - Time that all PSH at maximum/minimum approximately doubles, to about 500 hours/year. Suggests additional capacity is not required.
- 1 hour Schedule Capability
  - In general, an economically rational unit commitment that includes the intermittent resource forecasts results in a schedule range capability that meets requirements
  - No simultaneous extremes of high net load change and low schedule flexibility occurred
  - Hydro contributes significantly to schedule flexibility
    - Hydro maneuverability, even during heavy run-off (e.g. spring 2006), is still substantial

Observations by Time Frame: Load Following/Economic Dispatch (5 Minute)

- 5 Minute Variability and Load Following Requirement (3σ)
  - In general, load following requirement increases about 7%, or by 43 MW per 5 minutes, to ~670MW
  - For light load, load following requirement increases about 20% (to ~340MW)
    - This is 55% of ~620MW year-round requirement w/o intermittent renewables
  - Switching of PSH contributes significantly to load following duty at light load
    - For load only, PSH switching increases requirement by about 25% to ~290MW
    - Intermittent renewables (primarily wind) increase requirement by about the same
- Load Following and Ramping Capability
  - In general, an economically rational unit commitment that includes the intermittent resource forecasts results in ramp up and down capability that meets requirement
  - No risk of insufficient ramp rate up capability was identified
  - Under light load, hydro provides the majority of ramp down capability
    - At high run-off other resources provide significant ramp down capability
  - Ramp down capability may be stressed/depleted under some light load conditions
    - Wind > 10,000 MW less than 1% of time; on rare occasions mitigation may be required

Observations by Time Frame: Load Following/Economic Dispatch (5 Minute) - Continued

- Implied costs
  - In general, since economically rational UC provides sufficient LF capability, there is no market inefficiency, and therefore no incremental cost, associated with the incremental LF requirement.
  - In the worst case, if incremental LF duty shifted to regulation then regulation cost would increase between 7 and 48 ¢ / MWhr of intermittent renewable

Observations by Time Frame: Regulation (1 minute)

- 1 minute variability and regulation requirements
  - In general, requirement for procured regulation is essentially unchanged
    - Statistics and QSS show an increased requirement for regulation in the range of 10 to 20MW
    - CPS2 violations would be expected to increase about 1-2%, if no additional regulation provided
  - For light load
    - Switching of PSH contributes significantly to regulation duty at light load
    - Incremental regulation requirement at light load is about the same as year round requirement
- Regulation Capability
  - Present range of procured regulation, of approximately 300 to 600 MW up and 300 to 500 MW down, is much broader than required increases
- Implied costs
  - For example, 20MW additional regulation (up and down) is about
    - 21¢ / MW-hr of intermittent renewable

Conclusions

- System operation with 12,500 MW of wind generation and 2,600 MW of solar is feasible with 2010X scenario infrastructure. 2020 scenario will be easier.
- An economically rational unit commitment must include intermittent resource forecasts.
- Such a commitment results in sufficient flexibility for successful operation.
- Some operating conditions will be more challenging:
  - Periods of high load rise, such as winter evening peak, may see an increased rate of rise.
  - Periods of light load will increase in frequency, and when combined with extremely high wind, may require mitigation (e.g., curtailment).
- Requirements for load following and regulation increase, resulting in increased duty for the balance of the generation portfolio. Possible additional cost for increased regulation ranges from 0 to 69 ¢ / MWhr of intermittent renewable.
- Changes in revenue are likely to affect economic viability of incumbent generators. It is possible that some will exit.
- Variable cost of production, wholesale load payments, total emissions and natural gas consumption drop substantially.
- Mitigation schemes examined in the study will be beneficial for challenging operating conditions, and can be pursued on an incremental and systemic basis.

Recommendations

- Proceed with renewable generation plans, including large scale incorporation of intermittent resources
- Incorporate intermittent resource forecast into unit commitment
  - Implement process for continuous validation and improvement of forecasts
- Develop operating strategies for challenging periods. Market structure (e.g. ancillary services, capacity market, incentives) must enable use of existing operational flexibility
- Perform complete transmission planning and engineering studies, to ensure that the bulk power system can successfully accommodate individual projects.
- Prepare for retirements. Market structure and policy should ensure sufficient operational flexibility and reward the provision of maneuverability and mitigation capability
- Approach renewable integration challenges on a statewide and systemic basis